Chapter 4
Solidification/Stabilization (Ex Situ/In Situ)

4-1. General

The process of solidification/stabilization, ex-situ methods, in-situ methods, binding agents, and applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

4-2. Technology Description

a Process of Solidification/Stabilization.

Solidification/stabilization is the use of various chemical additives (Portland cement, kiln dust, and fly ash) to chemically bind and immobilize contaminants or to micro-encapsulate them in a matrix that physically prevents mobility. Solidification generally refers to a physical process where a semi-solid material or sludge is treated to render it more solid. Stabilization typically refers to a chemical process that actually binds the matrix of the contaminant such that its constituents are immobilized. Functionally, these processes either chemically bind or physically trap the contaminants. The terms *solidification* and *stabilization* refer to the formation of chemically as well as physically stable matrices. Solidification and stabilization can be done in-situ or ex-situ.

b Ex-situ Methods.

Field processes involve excavation and staging of the solids, screening to remove materials too large in diameter to be effectively treated (often 2 inches in diameter or greater), blending the binding agents and water with solids (typically in a pug mill), and stockpiling treated solids for testing prior to shipment off site or placement back in the excavation. Solidification/stabilization is most effective on metals and inorganic contaminants, and less effective with increasing concentrations of organic contaminants. Figure 4-1 illustrates the in-situ and ex-situ solidification/stabilization processes. Solidification/stabilization can result in monolithic-formed blocks or chunks, or in a soil-like matrix.

A significant consideration in applying the ex-situ technology is the "swell factor" in the solid volume created by the binding agent; this factor depends on the amount of reagents that must be added and can approach 50% in some cases. Not all of the treated material may fit in the same excavation from which it was removed without altering the natural grade.

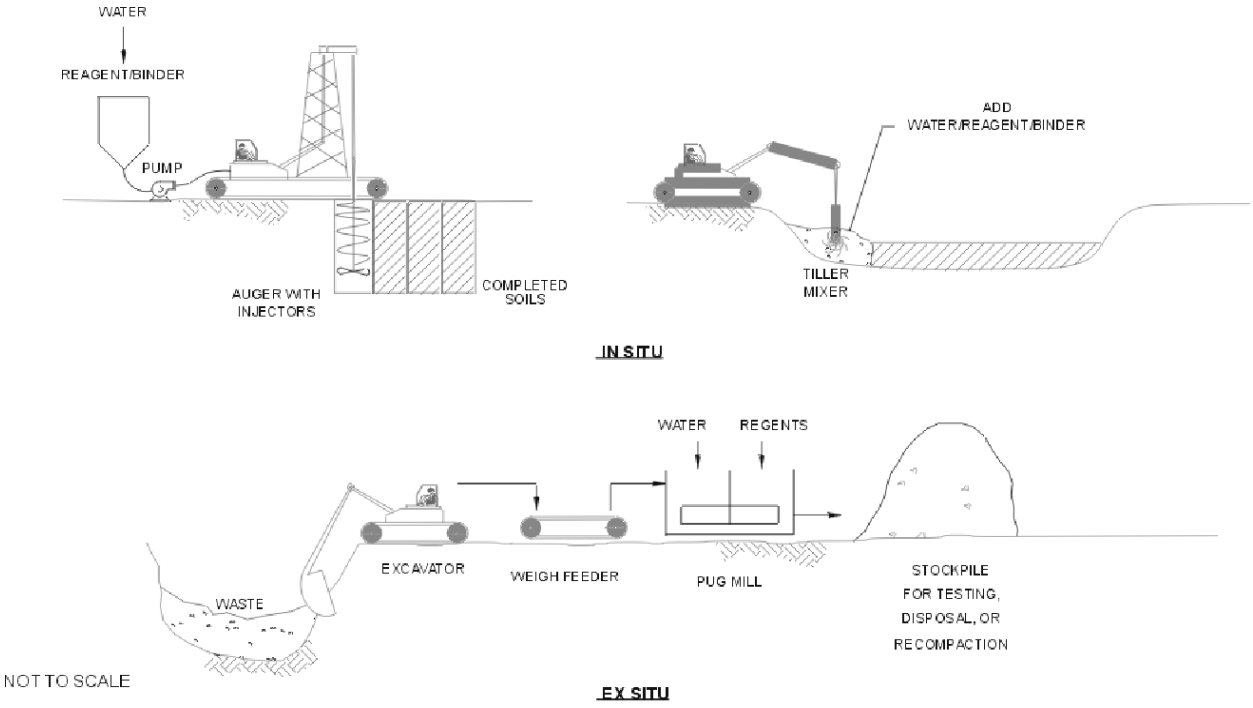

FIGURE 4-1. SOLIDIFICATION/STABILIZATION (IN SITU/EX SITU)

c. In-situ Methods.

In-situ solidification/stabilization involves the injection or mixing of stabilizing agents into subsurface soils to immobilize the soil matrix and contaminants to prevent leaching into infiltrating precipitation or groundwater. Typically, in-situ stabilization involves the addition of binding agents to an area of sludge or soils, addition of water if necessary, and then repeated in-place mixing with the bucket of a back or track hoe to thoroughly mix and stabilize the sludges or soils in place. A growing method of in-situ solidification/stabilization is the use of very large flighted rotary augers, 6–8 or more feet in diameter, capable of injecting slurry chemicals and water through the auger flights. The auger bores and mixes a large diameter "plug" of the contaminated material. During augering, stabilization chemicals and water (if needed) are injected into the soils. After thorough mixing, the auger is removed and the setting slurry is left in place. The auger is advanced to overlap the last "plug" slightly and the process is repeated until the contaminated area is completed. The solidification/stabilization additives are the same as with other in-situ or ex-situ techniques, but the process provides better in-situ mixing and distribution of additives.

d. Binding Agents.

Typical binding/stabilizing agents (in-situ or ex-situ) include Portland cement, pozzolanic binders, and various kiln dusts. Most of these materials are highly alkaline, and form a solidified matrix when mixed with the contaminated material.

Ex-situ solidification/stabilization uses the same kinds of binding/stabilizing agents as those used in-situ, but solids are excavated and treated in mixing equipment, such as pug mills or cement mixers outside the original waste locations. The material handling requirements of this approach are greater than for in-situ methods, but the degree of mixing and blending control is significantly higher than for in-situ processing. This generally yields higher confidence that the contaminants have been effectively immobilized and may require less reagent per unit volume of solids treated.

e. Applications.

The solidification/stabilization process has been successfully demonstrated and used for inorganic contaminants, primarily metals, and radionuclides in the presence of low levels of organic materials. The process is not considered routinely applicable for situations where the organic content of the wastes/soil, as measured by total petroleum hydrocarbons (TPH), is greater than 5,000–10,000 mg/kg because the organic material has leached out of the cement matrix over several years in some cases. The addition of activated carbon and other adsorbents can enhance the levels of organics practically treatable with this technology.

4-3. Hazard Analysis

Principal unique hazards associated with solidification/stabilization (ex-situ/in-situ), methods for control, and control points are described below

a. Physical Hazards.

(1) *Equipment Hazards*.
Description. During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders, tillers, scrapers, and other equipment.

Control. Controls for equipment hazards include:

- Use heavy equipment with a backup alarm to alert workers.
- Equip workers near heavy equipment with fluorescent orange or lime green traffic vests.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Train workers in the unique operational hazards and safety features of the heavy equipment.

CONTROL POINT: Construction, Operations

(2) *Auger/Caisson Hazards*.
Description. Installation of auger/caisson systems poses mechanical hazards owing to the use of large rotating augers. During the in-situ stabilization process, heavy equipment and materials, such as augers and caissons, are periodi-

cally raised overhead and placed into position. Workers may be exposed to swinging equipment or crushing hazards if the equipment falls.

Control. Controls for auger/caisson hazards include:

- Establish a work zone and allow only those personnel necessary for the task in the zone.
- Inspect lifting equipment regularly and operate safely.
- Raise equipment only as high as needed and minimize the movement of raised equipment.
- Avoid contact with auger edges, cables, and pipe and wear appropriate personal protective equipment (PPE), including hard hats, steel-toe shoes, instep guards, and appropriate clothing.
- Only allow trained and authorized workers within the swing radius and work areas around the equipment.

CONTROL POINT: Construction, Operations

(3) *Rotating Equipment Hazards*.
Description. Rotating augers or backhoes pose hazards to workers as loose clothing may become entangled with the revolving augers.

Control. Controls for rotating equipment include:

- Secure all loose clothing.
- Stay clear of rotating and moving equipment.
- Allow only trained and authorized workers near the equipment.

CONTROL POINT: Construction, Operations

(4) *Utility Contact Hazards*.
Description. Fire and explosion hazards may exist when using augers or other drilling methods if the auger contacts or ruptures underground utilities, such as electric or gas lines, or underground tanks. Also, underground obstructions, such as sewers and foundations, may cause drilling equipment to abruptly stop, resulting in unsafe drilling conditions. Electrocution hazards may also exist if large stabilization augers come in contact with overhead electrical wiring during placement or operation.

Control. Controls for utility contact hazards include:

- Train the operators in the hazards of excavating in the vicinity of underground or overhead utilities.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency excavation and auger isolation procedures.
- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel. When there is any doubt or uncertainty, carefully excavate with a backhoe, probe with a metal

rod, or hand excavate to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to direct the raising of a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Operations

(5) *Unguarded Moving Mechanisms.*
Description. Pug mills and similar equipment used to mix soils may be equipped with unguarded drive shafts, sprockets, chains, pulleys, or other revolving/rotating mechanisms. Exposure to the unguarded equipment may result in workers becoming entangled.

Control. Controls for unguarded moving mechanism include:
- Guard all moving mechanisms to prevent accidental contact.
- Operate equipment only when guards are in place.
- Wear appropriate PPE and clothing. No loose clothing should be worn, shirt tails should be tucked in, and long sleeves should be buttoned.
- Restrain long hair under hard hats.
- Train workers in the unique hazards associated with unguarded machinery and rotating powers shaft pinch and entanglement points.

CONTROL POINT: Design, Construction, Operations

(6) *Explosive Gases*.
Description. Solidification/stabilization can sometimes cause off-gassing of dangerous substances. As an example, when quantities of magnesium are present, solidification/stabilization with cement will cause off-gassing of hydrogen from a water–magnesium reaction and present a fire and explosion hazard. This can be a problem with stabilization in drums and other containers.

Control. Controls for explosive gases include:
- Train the operators in the hazards of the chemistry of all contaminants and potential reactants involved in the soil matrix being prepared by solidification/stabilization.
- Train the operators in emergency procedures in the event of a catastrophic event, in life saving first aid procedures for burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency reactant isolation procedures.
- Evaluate during design what off-gases, if any, to expect.
- Ventilate the work areas where stabilization is taking place.
- Monitor as necessary for explosive gases.

CONTROL POINT: Design, Construction, Operations

(7) *Steam Pressure Washing.*

Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:

- Uses insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Equip washer with deadman or kill switch if not provided by the manufacturer.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations

(8) *Respirable Quartz Hazard*.

Description. Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz potential, sample and analyze site soils for fines content by ASTM D422 (2002): "Standard Test Method for Particle Size Analysis of Soils" followed by analysis of the fines by X-ray diffraction to determine crystalline silica quartz content.

Control. Controls for respirable quartz include:

- Wet the soil periodically with water or amended water to minimize worker exposure. Consult 29 CFR 1910.1000, Table Z-3, to calculate acceptable respirable dust concentrations based on percent silica in the quartz.
- Use respiratory protection, such as an air-purifying respirator equipped with an N, R or P100 particulate air filter.
- Train workers in the potential hazards associated with inhalation exposures to crystalline silica.

CONTROL POINT: Construction, Operations

(9) *UV Radiation*.

Description. During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control. Controls for UV radiation include:

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen. Loose clothing and sun hats should not be worn around moving parts or close to operating equip-

ment that may snag the worker and draw him or her into a danger zone. All UV skin barrier creams should be pre-approved. Some creams contain zinc and other constituents that can cause false readings in analytical samples.

- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and working during the early morning and late afternoon hours.
- Use the Buddy System and provide easy access to water.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Construction, Operations

(10) *Electrocution Hazards*.
Description. Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control. Controls for electrocution hazards include:

- Verify the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs, at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.

CONTROL POINT: Design, Construction, Operations

(11) *Heavy Equipment Hazards*.
Description. The heavy equipment (small and large) used for site operations may roll over on steep slopes or unstable ground, crushing the operator.

Control. Controls for heavy equipment hazards include:

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction (construction contractor).
- Use heavy equipment with roll-over protective devices (ROPS) and do not operate on steep slopes or unstable ground.
- Train workers in the hazards associated with heavy equipment and the safety features built into the equipment.

CONTROL POINT: Design, Construction, Operations

(12) *Traffic Hazards*.

Description. During field activities, equipment and workers may come close to traffic. Also, drilling rigs and other equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control. Controls for traffic hazards include:

- Post warning signs where equipment crosses roads according to the criteria of the "Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways."
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21, provides plan details.

CONTROL POINT: Design, Construction, Operations

(13) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle strain include:

- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques, including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14).

CONTROL POINT: Design, Construction, Operations, Maintenance

(14) *Noise Hazards*.
Description. Both in-situ and ex-situ solidification/stabilization systems may present a noise hazard to workers.

Control. A control for noise hazards includes:

- Wear hearing protection in accordance with 29 CFR 1910.95 and 29 CFR 1926.521 requirements as necessary around operating equipment.
- Institute a hearing conservation program for the workers.

CONTROL POINT: Construction, Operation

(15) *Emergency Wash Equipment.*
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:

- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(16) *Design Field Activities.*

Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include:

- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) *Contamination Hazards.*

Description. During excavation and mixing operations (in-situ or ex-situ), workers may be exposed to inhalation/ingestion/dermal hazards from airborne contaminated dusts, VOCs, and waste materials. These materials may include: portland cement, quicklime, hydrated lime, kiln dust, fly ash, sodium silicate, and gypsum. Stabilizers such as quicklime will induce an exothermic reaction in the presence of organic materials in the waste and water, creating a potential chemical/thermal hazard exposure. Also, the addition of cement may result in chemical release to the air from chemical reactions with waste materials. Eye exposure to airborne dusts and chemicals may occur, resulting in irritation, scratching, and scarring of eyes. High-pressure injection of stabilizing compounds can spray or splatter chemical agents that may also cause eye damage.

Control. Controls for contamination hazards include:

- Reduce airborne contaminants by applying water periodically to the active excavation and mixing areas.
- Use injection equipment with pressure-trip interlocks to prevent operation at excessive pressures.
- Select the proper types of PPE: an air-purifying respirator with approved N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Wear eye protection.
- Offer frequent health and safety awareness meetings.
- Use experienced workers and decontamination stations.

CONTROL POINT: Design, Construction, Operations

(2) *Chemical Exposure*.
Description. During the excavation process, accidental rupturing of underground utilities, such as sewers and pipelines containing gases and liquids, may result in worker exposure to chemicals.

Control. Controls for chemical exposure include:

- Identify underground utility location by contacting local utilities and public works personnel.
- Locate the below-ground utilities and probe with a metal rod prior to excavating to prevent underground rupture.

CONTROL POINT: Construction, Operations

(3) *VOCs Exposure*.
Description. Enhanced off-gassing of VOCs may occur as a result of the heat generated during the stabilization process. Also, ammonium compounds may release ammonia when mixed with cement. Workers may be exposed to VOCs via inhalation or dermal exposure routes.

Control. Controls for VOCs exposure include:

- Reduce airborne VOCs by the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas to which foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and portable surface covers.
- Use the proper types of PPE: an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings; use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Operations

c. Radiological Hazards

Contaminant Hazards.
Description. Contaminants in excavated or in-situ soils, sludge, and associated water may pose a rare radiation hazard. Naturally occurring radioactive material (NORM) may be present in the soils, sludge, and groundwater. Some radioactive materials are pyrophoric. Radioactive materials of uranium or thorium may spontaneously ignite and pose a fire hazard and an airborne radioactivity hazard. Buried radioactive materials may present an external hazard. All radioactive materials may present an internal hazard through inhalation or ingestion.

Control. Controls for contaminant hazards include:

- Test soil, sludge, and water to identify and eliminate exposure potential during excavation, classification, and disposal. A qualified health physicist should determine the presence of radiation or particulate radioactive materials, and their nature and extent.
- Use appropriate engineering, PPE, and other controls to prevent exposure.
- Make decontamination facilities available to help minimize exposure.
- Suppress dust and other emissions using periodic applications of water or amended water.

CONTROL POINT: Design, Operations

d. Biological Hazards.

(1) *Biological Contaminants.*
Description. At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.*

Control. Controls for biological contaminants include:

- Test for microorganisms in the soil and determine the appropriate PPE to help control exposure.
- Reduce the generation of airborne contaminants, including microbes and particles (dust), with the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Use the proper types of PPE: an air-purifying respirator equipped with approved N, R or P100 or N, R or P95 particulate air filters approved for microbial inhalation hazards, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings; use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Construction, Operations

(2) *Pests*.
Description. Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus. Mosquitoes can transmit the West Nile Virus.

Control. Controls for pests include:

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents containing N,N-diethyl-m-toluamide (DEET) 25% as the active ingredient for exposure control. Clothing may be treated with permethrin clothing repellent BEFORE donning, for added protection. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Construction, Operations, Maintenance